Seedling Development and Field Performance of Prairiegrass, Grazing Bromegrass, and Orchardgrass

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ABSTRACT

Seedling establishment is a critical phase in pasture management. Knowledge of the seedling development of new forages is necessary to develop management practices and recommend species mixtures for pasture seedings. We compared seedling growth and development of prairiegrass (*Bromus willdenowii* Kunth = *B. catharticus* Vahl), grazing bromegrass (*B. stamineus* Desv.), and orchardgrass (*Dactylis glomerata* L.) in controlled environment and field studies. Seedlings were sampled weekly for 7 wk in the growth chamber and greenhouse beginning 8 to 10 d after planting (DAP). The number and mass of leaves and roots were recorded. In the field, leaf development was measured during spring and fall of 1997, and leaf and root development were measured during spring and fall of 1999. Forage dry matter (DM) yield was measured in clipped field plots during 1998 to 2000. Grazing bromegrass had more leaves, about twice the number of tillers per seedling, and a greater seedling mass than other grasses. Grazing bromegrass also had 50 to 100% more tillers m^{-2} than other grasses in clipped field plots. The larger seedling size and greater tiller density, however, did not translate into greater yield in clipped plots. Grazing bromegrass yielded 10 to 15% less than orchardgrass or prairiegrass. Because of their large seedlings and rapid development, prairiegrass and grazing bromegrass probably should be used at a lower seeding rate or perhaps not used in seed mixtures with small-seeded grasses. Seedlings of these grasses should be fully established by 40 to 50 DAP under favorable moisture and temperatures in the spring and late summer.

Cool-season grasses, such as orchardgrass, predominate in the pastures and haylands of the northeastern USA (Baylor and Vough, 1985). Orchardgrass is commonly recommended for pastures in the Northeast because of its better drought tolerance and winterhardiness compared with perennial ryegrass (*Lolium perenne* L.) (Van Santen and Sleper, 1996; Christie and McElroy, 1994). Growth of these grasses follows the well-known bimodal distribution of peak growth in late May and early June, slower growth during July, August, and early September, with another increase in growth during mid-September and October. Finding forage species to fill the forage deficit periods and successfully establishing these species from seed are critical needs for graziers.

Prairiegrass has been investigated for use in pastures in the northeast because of its extended growth in the fall (Hall et al., 1996). It has a relatively high seed mass, which aids in emergence and establishment (Andrews et al., 1997). Grazing bromegrass recently has been introduced as a cool-season species for grazing (Stewart, 1992). *Bromus stamineus* is adapted to light soils where drought is likely and to frequent and intensive grazing (Stewart, 1992). Thus, *B. stamineus* may have value in providing forage during midsummer, but not much is known about its establishment, yield, and adaptation in the northeastern USA.

Seedling establishment is a critical phase in pasture production. Rapid development of a critical number of roots along with the development of leaf area and mass are necessary to ensure seedling survival. Perennial grasses are considered established when four to six leaves and at least two adventitious roots have developed on the seedling (Ries and Svejcar, 1991). Knowledge of the growth and development of new forages is necessary to design appropriate management practices and formulate potential species mixtures for pasture seedings. The objective of this research was to develop fundamental information on the growth and seedling development of prairiegrass, grazing bromegrass, and orchardgrass during establishment and relate this information to forage production in subsequent years.

MATERIALS AND METHODS

Greenhouse and Growth Chamber Experiments

In the greenhouse, five seeds of 'Gala' grazing bromegrass, 'Matua' prairiegrass, and 'Pennlate' orchardgrass were planted 1-cm deep in 5-cm diameter × 21-cm deep containers filled with potting soil (Scots-Sierra Horticultural Products Co., Marysville, OH[1]). Seedlings were thinned to one per container soon after emergence. Containers (105 of each entry) were planted on 24 Jan. 1997 and entries were grouped into five replicates with 21 containers of each entry per replicate. The experimental design was a randomized complete block. Beginning 10 DAP, three containers per replicate of each entry were sampled destructively each week for 7 wk. Temperature in the greenhouse varied from 23 to 41 °C during the day and 13 to 24 °C night. Relative humidity ranged from 10 (day) to 100% (night). Natural light was supplemented (but the natural daylength was not extended) with artificial light from 400-W lamps providing 260 μmol photosynthetic photon flux density m^{-2} s^{-1} at plant height during the experiment. Red/far-red ratio of the supplemental light was 1.61 compared with 1.31 for natural light levels.

The same planting procedures were used for the growth chamber experiment, except that the 15 containers of each entry sampled each week were considered individual replicates. An additional orchardgrass cultivar, 'Dawn', was added. Washed sand was used as the growing medium. Because of the number of containers, three growth chambers were used and treatments were blocked by chambers and within chambers. Beginning 8 DAP on 9 Feb. 1998, 15 replicates of each entry were sampled destructively each week for 7 wk. Temperatures in the growth chambers were maintained at 25 °C day

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[1] Mention of a trade name does not imply endorsement by the USDA-ARS.

Abbreviations: DAP, days after planting; DM, dry matter.

and 15 °C night, with a 16-h daylength and 50 to 70% relative humidity. Light in the chambers was provided by a mixture of incandescent and fluorescent bulbs at 216 μmol photosynthetic photon flux density m^{-2} s^{-1} with a red/far-red light ratio of 1.6. Plants were watered daily with half-strength Hoagland's solution.

At each destructive sampling in each experiment, the number of tillers per plant and leaves per tiller were counted, plants were removed from the container, and the soil or sand was washed from the roots in cold running water. Root length was measured from the crown node to the tip of the longest root. Shoots and roots were separated at the crown node and dried at 55 °C for 48 h to determine dry weight.

The greenhouse and growth chamber experiments were analyzed as randomized complete block designs. Separate analyses of variance were conducted for each sampling date. Preplanned orthogonal comparisons were used to compare treatment means at each sampling date. The comparisons for the greenhouse experiment were (i) Matua prairiegrass and Gala grazing bromegrass vs. Pennlate orchardgrass, and (ii) Matua prairiegrass vs. Gala grazing bromegrass. The comparisons for the growth chamber experiment were (i) Matua prairiegrass and Gala grazing bromegrass vs. orchardgrass cultivars, (ii) Matua prairiegrass vs. Gala grazing bromegrass, and (iii) Dawn vs. Pennlate orchardgrass. In both experiments, least squares means along with the standard errors were plotted against sampling date to illustrate seedling development.

Field Experiments

Two field studies were conducted during 1997 to 2000 at the Russell E. Larson Agricultural Research Center near Rock Springs, PA, to determine seedling developmental patterns and subsequent yield performance of the grasses under clipping. Soil at the site was a Hagerstown silt loam (fine, mixed, semiactive, mesic Typic Hapludalfs).

1997 to 1999 Field Experiment

Soil tests in 1997 indicated a pH of 6.3, 59 kg ha^{-1} of available P, and 220 kg ha^{-1} of available K. Limestone was applied at 4.5 Mg ha^{-1} in May 1997. No other fertilizer was applied during the seedling development phase of the study in 1997. Pennlate and Dawn orchardgrass, Gala grazing bromegrass, and Matua prairiegrass were seeded with a plot drill in 4- by 6-m plots on 16 May 1997 in a clean tilled seed bed. Matua was planted at 30 kg ha^{-1}, Gala at 20 kg ha^{-1}, and orchardgrass at 6 kg ha^{-1}. The seeding was repeated on 19 Sept. 1997 on an adjacent site with the same species, cultivars, and cultural methods, except that plot size was 2 × 3 m. Plots were sown in five replicate blocks.

Seedling emergence was monitored weekly for both plantings. Seedlings in all plots had emerged by 28 May for the spring planting and 29 September for the fall planting. Thirty seedlings were selected at random in each plot at 21, 37, 47, 61, and 74 DAP for the spring seeding and 17, 24, 31, 35, 42, and 49 DAP for the fall seeding. The number of fully expanded leaves was counted on the main stem of each selected seedling at each date, and a note was made if the seedling had tillered. The arithmetic average of the 30 observations per plot was calculated to determine the mean leaf development stage. Separate analyses of variance were conducted for each sampling date. Preplanned orthogonal comparisons were used to compare treatment means at each sampling date. The comparisons were (i) Matua prairiegrass and Gala grazing bromegrass vs. orchardgrass cultivars, (ii) Matua prairiegrass vs. Gala grazing bromegrass, and (iii) Dawn vs. Pennlate orchardgrass. The least squares means along with the standard error were plotted against sampling date to illustrate seedling development.

Table 1. Harvest dates of grasses in 1998, 1999, and 2000. Grasses were harvested on a 3- or 5-wk schedule in 1998 and 1999. Harvests were made on a 4-wk schedule in 2000.

1998		1999		2000
3-wk	5-wk	3-wk	5-wk	
19 May	19 May	20 May	20 May	8 May
10 June	24 June	10 June	24 June	7 June
30 June	29 July	1 July	29 July	3 July
21 July	2 Sept.	22 July	2 Sept.	31 July
11 Aug.	7 Oct.	12 Aug.	7 Oct.	29 Aug.
2 Sept.		2 Sept.		
23 Sept.		23 Sept.		

Spring-sown plots were harvested for DM yield during the production phase in 1998 and 1999. The 4- by 6-m plots were divided lengthwise, and one-half was harvested on a 3-wk interval and the other half was harvested on a 5-wk interval. The harvest dates are listed in Table 1. At each harvest, a 0.51- × 4.6-m strip was cut to a 7-cm height with a rotary mower equipped with a bag to collect clippings. The entire sample was dried at 55 °C for 48 h to determine DM yield. Tillers were counted in two 0.1-m^2 quadrats in each plot at each harvest (except for the first) in 1999. Plots were fertilized with 27 kg P and 72 kg K ha^{-1} in late fall 1997 and April 1999. Fertilizer N was applied at 56 kg ha^{-1} in June and July of both 1998 and 1999.

The experimental design for the seedling development phase was a randomized complete block in five blocks (replicates). The design for the DM yield phase in 1998 and 1999 was a split-plot arrangement of treatments in a randomized complete block with five blocks. Whole plots were the grass entries and subplots were harvest frequencies. Analysis of variance was conducted on total seasonal DM yield. Separate analyses of variance were conducted on the tiller density data for each harvest date. Preplanned orthogonal comparisons were used to compare treatment means. The comparisons were (i) Matua prairiegrass and Gala grazing bromegrass vs. orchardgrass cultivars, (ii) Matua prairiegrass vs. Gala grazing bromegrass, and (iii) Dawn vs. Pennlate orchardgrass.

1999 to 2000 Field Experiment

A second field study was planted on 28 Apr. 1999 and 28 Aug. 1999 with Dawn and Pennlate orchardgrass, Matua and 'Luprime' prairiegrass, and Gala and 'Feeder' grazing bromegrass. The field site was adjacent to the 1997 experiment. Soil tests in 1999 indicated a pH of 6.1, 87 kg ha^{-1} of available P, and 120 kg ha^{-1} of available K. Plot size was 2 by 4.6 m, and cultural methods were the same as for the fall 1997 planting. Seedlings emerged in all plots by 8 May for the spring planting and by 9 September for the late-summer planting. Fifteen seedlings were excavated to a 30-cm depth from each plot at 21, 27, 35, 48, 62, and 76 DAP in the spring and fall. The number of leaves per plant and shoot dry mass was determined at each harvest. Soil was washed from the roots under cold running water, and root mass, length, and number were measured at 21, 35, and 76 DAP in the spring and fall.

Spring-sown plots were harvested to determine DM yield every 4-wk during May to August 2000. Harvest procedures were the same as for the 1997 experiment. Tillers were counted in two 0.1-m^2 quadrats per plot in November 1999, April 2000, and October of 2000. Limestone was applied at 2 Mg ha^{-1} in April 2000. Fertilizer N was applied at 56 kg N ha^{-1} in April, June, and July of 2000.

The experimental design for the seedling development phase

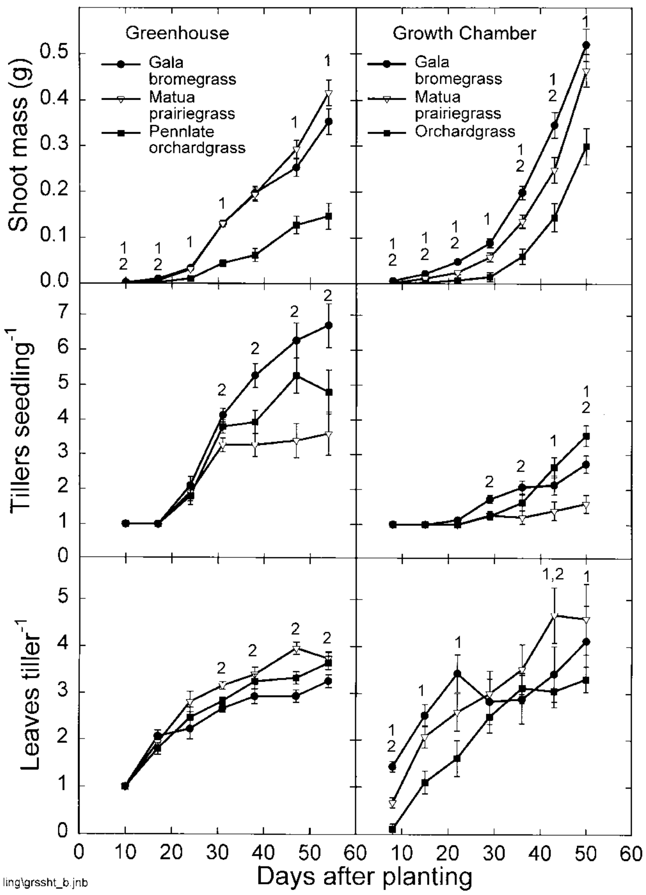

Fig. 1. Shoot attributes of Gala grazing bromegrass, Matua prairiegrass, and orchardgrass in the greenhouse and growth chamber. Each data point is the least-squares mean of 15 observations in each experiment. Error bars are two standard error units. Some error bars may not be visible because they are smaller than the symbols. Numbers at each date indicate significant ($P < 0.05$) contrasts: (1) Matua prairiegrass and Gala grazing bromegrass vs. orchardgrass, and (2) Matua prairiegrass vs. Gala grazing bromegrass.

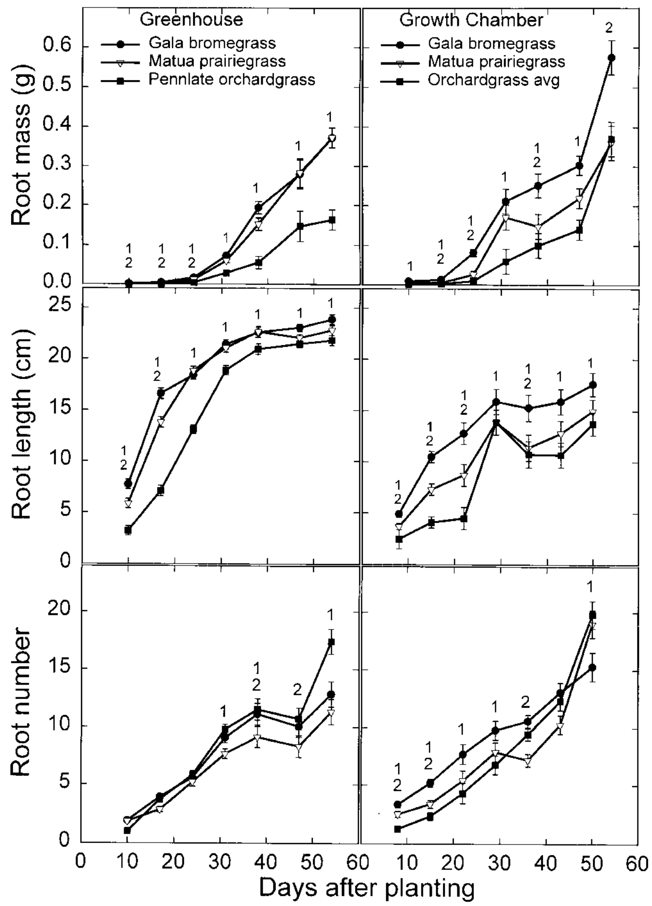

Fig. 2. Root attributes of Gala grazing bromegrass, Matua prairiegrass, and orchardgrass in the greenhouse and growth chamber. Each data point is the least-squares mean of 15 observations in each experiment. Error bars are two standard error units. Some error bars may not be visible because they are smaller than the symbols. Numbers at each date indicate significant ($P < 0.05$) contrasts: (1) Matua prairiegrass and Gala grazing bromegrass vs. orchardgrass, and (2) Matua prairiegrass vs. Gala grazing bromegrass.

and production phase was a randomized complete block with five blocks (replicates). A combined analysis of variance for the data on seedling attributes indicated no planting date × grass entry interaction ($P > 0.05$). Therefore, data were combined across the spring and late-summer planting dates and analyzed by sampling date. Analysis of variance was conducted on total seasonal DM yield. Separate analyses of variance were conducted on the tiller density data for each of the three counting dates. Preplanned orthogonal comparisons were used to compare treatment means. The comparisons were (i) orchardgrass cultivars vs. all other grasses, (ii) Dawn vs. Pennlate orchardgrass, (iii) prairiegrass cultivars vs. grazing bromegrass cultivars, (iv) Matua vs. Luprime prairiegrass, and (v) Gala vs. Feeder grazing bromegrass. Least squares means along with the standard errors were plotted against sampling date to illustrate seedling development. In all experiments, contrasts were declared to be statistically significant when $P < 0.05$.

RESULTS AND DISCUSSION

Seedling Development in the Greenhouse and Growth Chamber

Gala grazing bromegrass and Matua prairiegrass produced larger ($P < 0.05$) seedlings than orchardgrass in both the greenhouse and the growth chamber (Fig 1). The orchardgrass cultivars did not differ ($P > 0.05$) for any seedling attribute in the growth chamber. Matua produced significantly more leaves per tiller than Gala in the greenhouse. In the growth chamber, Gala produced more leaves per tiller than Matua early, whereas Matua produced more tillers on and after 30 DAP. Gala seedlings produced more total shoot mass because of greater tiller production than orchardgrass in the greenhouse. Matua produced fewer but larger tillers than orchardgrass in both controlled environments. Gala had twice ($P < 0.05$) the number of tillers per seedling than did Matua as noted also by Stewart (1992). Hume (1991) reported that Matua prairiegrass had a greater rate of leaf appearance, but a lower rate of tiller production than perennial ryegrass. In that study, perennial ryegrass produced a tiller at the coleoptile bud, whereas Matua did not, which contributed to its reduced tiller production.

Root mass relationships among grasses generally reflected differences in shoot mass both in the greenhouse and the growth chamber (Fig. 2). Both Matua and Gala

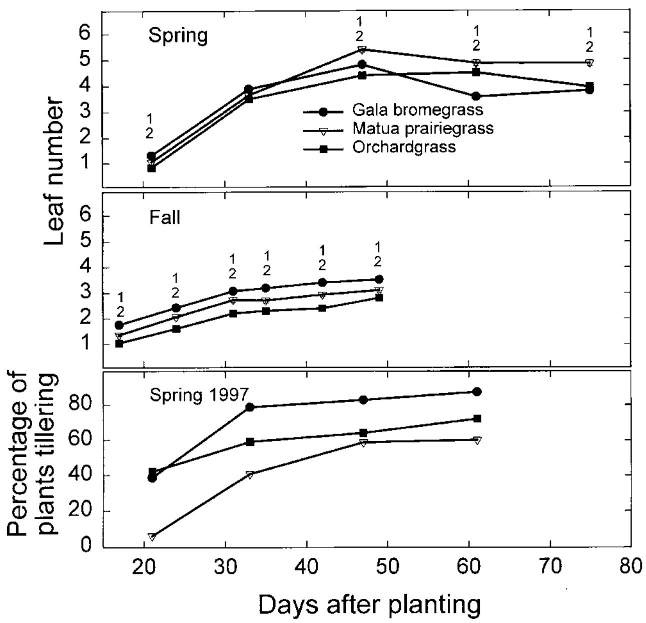

Fig. 3. Leaf development of Gala grazing bromegrass, Matua prairiegrass, and orchardgrass at Rock Springs, PA, in spring (May to July) and fall (September to November) of 1997. Each data point is the mean of five replicates and 30 seedlings per replicate. Error bars indicate two standard error units. Some error bars may not be visible because they are smaller than the symbols. Numbers at each date indicate significant ($P < 0.05$) contrasts: (1) Matua prairiegrass and Gala grazing bromegrass vs. orchardgrass cultivars, and (2) Matua prairiegrass vs. Gala grazing bromegrass.

developed a greater ($P < 0.05$) root mass and root length earlier than orchardgrass in the growth chamber. At the end of the experiments, however, orchardgrass had a greater number of roots than Gala or Matua. Shaffer et al. (1994) noted greater seedling growth and greater root production deeper in the soil with Matua prairiegrass than tall fescue (*Festuca arundinacea* Schreb.) and smooth bromegrass (*B. inermis* Leyss.) grown in containers outdoors. Other root characteristics such as root length density, diameter, and branching pattern also influence root function (Aguirre and Johnson, 1991).

Ries and Svejcar (1991) considered crested wheatgrass [*Agropyron desertorum* (Fisch. ex Link) Schult.] established when (i) the main stem had four leaves, (ii) there was at least one tiller on the main stem, and (iii) two adventitious roots developed. In our controlled environment experiments, all grasses met these criteria by 30 DAP in the greenhouse and 40 DAP in the growth chamber.

Although shoot mass of the grasses was relatively similar in both the greenhouse and the growth chamber, the grass seedlings had fewer tillers and leaves per plant in the growth chamber than in the greenhouse. This may be related to the lower air temperature and light levels in the growth chamber than in the greenhouse.

Seedling Development in the Field

1997 to 1999 Experiment

During the spring of 1997, Matua developed a greater number of leaves per tiller than the other grasses (Fig. 3). Dawn and Pennlate orchardgrass did not differ ($P > 0.05$) in mean leaf number in the spring or the fall. In each grass, the number of leaves per tiller decreased somewhat 45 DAP probably because some of the early leaves senesced. Gala had the greatest proportion of seedlings tillering in the spring, followed by orchardgrass and Matua. This ranking was the same in the greenhouse and growth chamber. At 45 DAP (33 d after emergence), all seedlings would have been considered established similar to the 46 DAP required for the establishment of crested wheatgrass in the northern great plains of the USA (Ries and Svejcar, 1991).

Gala produced more leaves per tiller in the fall than Matua and orchardgrass, which was similar to greenhouse results (Fig. 3). Seedling development in the fall of 1997 was slower than in spring, probably because of lower temperatures in the fall (Fig. 3, Table 2). Temperature, along with light quantity and quality, are major factors determining leaf appearance rate and tillering for cool-season grasses in the field (Hill et al. 1985; Hume, 1991).

The fall seedlings were not fully established, according to the criteria of Ries and Svejcar (1991). Fewer than 10% of Matua and orchardgrass seedlings had tillers, whereas 25% of Gala seedlings had at least one tiller (data not shown) at the end of the experiment. Visual observations of the fall-seeded plots in the spring of 1998 confirmed that none of the seedlings from the fall planting survived the winter, suggesting that plants were not fully established. White (1984) reported that winter injury was inversely related to the seedling leaf number for late-summer seeded cool-season grasses in the northern great plains of the USA.

Table 2. Air temperature, rainfall, and soil moisture at Rock Springs, PA, during 1997, 1998, 1999, and 2000.

	Average monthly air temperature					Rainfall					Soil moisture		
Month	1997	1998	1999	2000	30-yr mean	1997	1998	1999	2000	30-yr mean	1998	1999	2000
	°C					mm					$m^3\ m^{-3}$		
April	7.6	10.0	9.0	8.6	8.7	28	172	94	74	74		0.34	0.34
May	11.9	17.0	15.1	15.9	14.8	100	116	37	62	92		0.21	0.24
June	19.4	18.5	19.2	19.7	19.5	59	131	104	97	102	0.34	0.18	0.29
July	20.9	20.7	22.9	18.9	21.8	61	89	61	53	92	0.31	0.18	0.25
Aug.	19.1	20.9	19.4	19.1	20.9	171	71	146	74	81	0.26	0.23	0.28
Sept.	15.4	18.6	16.9	15.1	16.8	122	44	133	48	82	0.19	0.30	
Oct.	10.2	10.7	9.4		10.6	13	20	42		72	0.26	0.33	
Nov.	3.1	6.1	6.7		4.9	187	9	91		82	0.21	0.31	

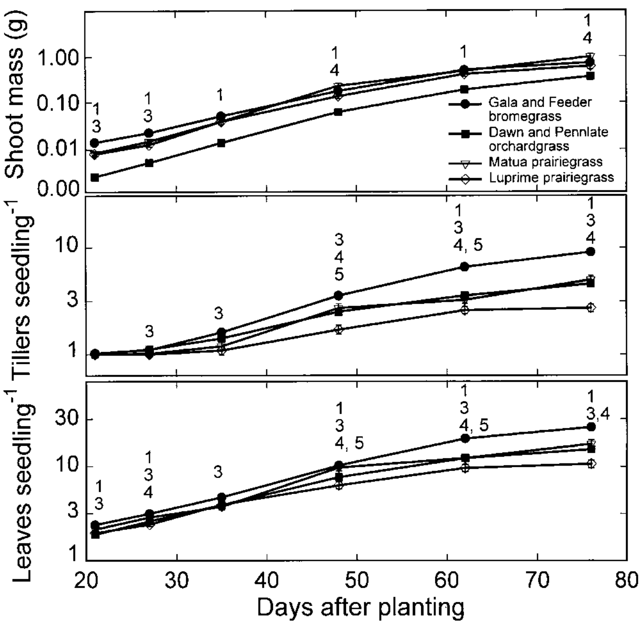

Fig. 4. Shoot attributes of grazing bromegrass, prairiegrass, and orchardgrass during 1999 in field plots at Rock Springs, PA. Each data point is the least-squares mean of two planting dates, five replicates, and 15 seedlings per replicate. Error bars indicate two standard error units. Some error bars may not be visible because they are smaller than the symbols. Data were nonnormally distributed and log10 transformed for analysis. Note that the *y* axis is on a log10 scale. Numbers at each date indicate significant ($P < 0.05$) contrasts: (1) Dawn and Pennlate orchardgrass vs. other grasses, (2) Dawn vs. Pennlate, (3) Gala and Feeder grazing bromegrass vs. Matua and Luprime prairiegrass, (4) Luprime vs. Matua, and (5) Feeder vs. Gala.

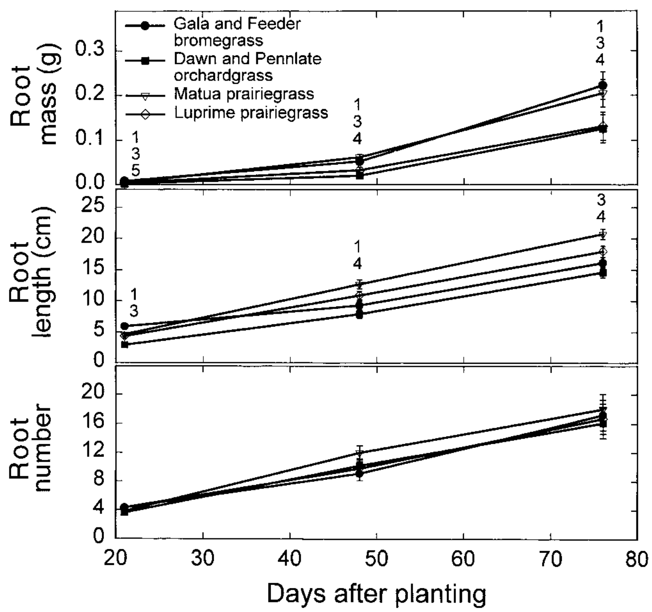

Fig. 5. Root attributes of grazing bromegrass, prairiegrass, and orchardgrass during 1999 in field plots at Rock Springs, PA. Each data point is the least-squares mean of two planting dates, five replicates, and 15 seedlings per replicate. Error bars indicate two standard error units. Some error bars may not be visible because they are smaller than the symbols. Numbers at each date indicate significant ($P < 0.05$) contrasts: (1) Dawn and Pennlate orchardgrass vs. other grasses, (2) Dawn vs. Pennlate, (3) Gala and Feeder grazing bromegrass vs. Matua and Luprime prairiegrass, (4) Luprime vs. Matua, and (5) Feeder vs. Gala.

1999 to 2000 Experiment

A combined analysis of variance revealed no interaction of planting date with grass entry, so means across planting dates are presented for grass entries. There were very few significant differences between grazing bromegrass or orchardgrass cultivars in seedling attributes, thus the means of cultivars of each of the species are presented. The bromegrasses and prairiegrasses had a greater seedling shoot mass than orchardgrass (Fig. 4), similar to greenhouse and growth chamber results. The bromegrasses developed several more tillers per plant than the prairiegrasses or the orchardgrasses, similar to the 1997 field results (Fig. 3) and the greenhouse and growth chamber results (Fig. 1). The bromegrasses also had a greater root mass and length by 76 DAP than other grasses in the field (Fig. 5). There were essentially no differences among grasses in root length. Matua and Luprime prairiegrass differed in shoot and root attributes with Matua developing a larger seedling with more leaves, tillers, and roots than Luprime.

All grasses in the spring and late summer plantings were established (according to Ries and Svejcar, 1991) by 47 DAP (37 d after emergence). Seedlings established in the late summer of 1999 survived the winter, as indicated by visual observation in the spring of 2000. We did not see a slower rate of establishment with the late-summer planting date in 1999 as we did with the fall planting date of 1997, probably because of higher temperatures and rainfall for the 1999 late summer planting compared with the fall 1997 planting (Table 2).

Yield Performance and Tiller Densities of Grasses after Establishment

Matua was the highest ($P < 0.05$) yielding grass in 1998 (Table 3). In 1999 and 2000, however, yields of prairiegrass and orchardgrass were similar. Gala yielded less ($P < 0.05$) than other grasses in 1998 and 1999. In 2000, yields of both Gala and Feeder were lower ($P < 0.05$) than other grasses. There was no cutting frequency by grass entry interaction for DM yield in 1998 and 1999, hence the decision to use one cutting frequency in 2000. Yield was lower ($P < 0.05$) for the 3-wk cutting frequency (9300 and 6800 kg ha^{-1} in 1998 and 1999, respectively) compared with the 5-wk cutting frequency (9900 and 7700 kg DM ha^{-1} in 1998 and 1999, respectively). Forage DM yields were lower in 1999 and 2000 than in 1998 probably because of lower rainfall and soil moisture in 1999 and 2000 (Table 2).

Tiller density peaked for nearly all grasses in early September under both clipping frequencies in 1999 (Fig. 6). Gala maintained twice as many tillers as Matua in June and October, and 50 to 60% as many tillers as Matua in late July and September under the 3-wk cutting frequency. There were fewer differences among grasses in tiller density under the 5-wk cutting frequency. Gala maintained 34% more tillers m^{-2} in September and 19%

Table 3. Forage dry matter yields of grasses during 1998, 1999, and 2000.

Grass	Dry matter yield†		
	1998	1999	2000
	kg ha^{-1}		
'Dawn' orchardgrass	9 700	7 400	7 400
'Pennlate' orchardgrass	9 700	7 700	7 200
'Gala' grazing bromegrass	8 300	6 400	5 400
'Feeder' grazing bromegrass			6 100
'Matua' prairiegrass	10 600	7 500	7 000
'Luprime' prairiegrass			7 100
SE	260	180	250
3-wk cutting interval	9 300	6 800	
5-wk cutting interval	9 900	7 700	
SE	220	136	
Preplanned contrasts			
Orchardgrass vs. others	NS‡	**	**
'Dawn' vs. 'Pennlate'	NS	NS	NS
'Matua' vs. 'Gala'	**	**	
Prairiegrass vs. bromegrass			**
'Matua' vs. 'Luprime'			NS
'Gala' vs. 'Feeder'			**

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
† Dry matter yield data in 1998 and 1999 are averages of two cutting intervals and five replicates. In 2000, dry matter yield data are means of five replicates for a 4-wk cutting interval.
‡ NS = not significant.

more ($P < 0.05$) tillers m^{-2} in October than did Matua or orchardgrass. For the 1999 planting, the bromegrasses and orchardgrass maintained 28% more ($P < 0.05$) tillers m^{-2} than did the prairiegrasses in November 1999 (Fig. 7). Tiller density was much lower for both prairiegrass and bromegrass than orchardgrass in April 2000, perhaps reflecting the earlier spring growth of orchardgrass. By October 2000, the bromegrasses had twice the tiller density of prairiegrass, whereas orchardgrass tiller density was intermediate.

SUMMARY AND CONCLUSIONS

Gala grazing bromegrass frequently maintained a greater number of tillers and leaves per seedling and a seedling mass equal to or greater than seedlings of other grasses in controlled environment and field experiments. During subsequent years, however, this did not translate into greater yield performance in clipped field plots. Cultivars of *B. stamineus* were developed for use under hard grazing and dryland conditions (Stewart, 1992; Sutherland, 1997). Our data showed that Gala grazing bromegrass did not perform as well as orchardgrass or prairiegrass under mechanical clipping in either dry (1999) or favorable (1998) soil moisture conditions. Greater tiller density did not seem to be an advantage under a more frequent clipping regimen. Others have found that the greater tiller density of Gala grazing bromegrass may improve its persistence, compared with Matua prairiegrass (Sutherland, 1997). The inability of grazing bromegrass to translate its rapid early tiller development and large seedling mass into greater yield performance in clipped field plots may be related to differences in tiller mass. In the controlled environment and field studies, prairegrass and orchardgrass tiller mass increased at similar rates over time (Fig. 8). Tiller mass of grazing bromegrass, however, increased at a much slower rate so that reduced tiller mass may have offset the increased tiller number. Tiller mass frequently is the main determinant of grass yield in established swards (Zarrough et al., 1983).

Both Matua prairiegrass and Gala bromegrass rapidly developed a larger seedling with a greater root mass and length than orchardgrass. Sangakkara et al. (1985)

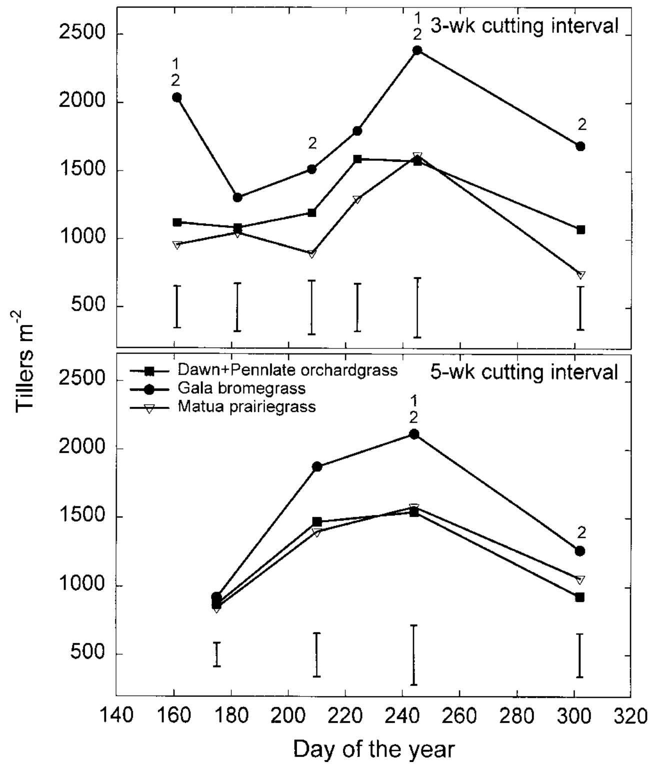

Fig. 6. Tiller density of grazing bromegrass, prairiegrass, and orchardgrass in the first field planting during 1999 at Rock Springs, PA. Error bars indicate two standard error units. Numbers at each date indicate significant ($P < 0.05$) contrasts: (1) Dawn and Pennlate orchardgrass vs. other grasses, and (2) Gala grazing bromegrass vs. Matua prairiegrass.

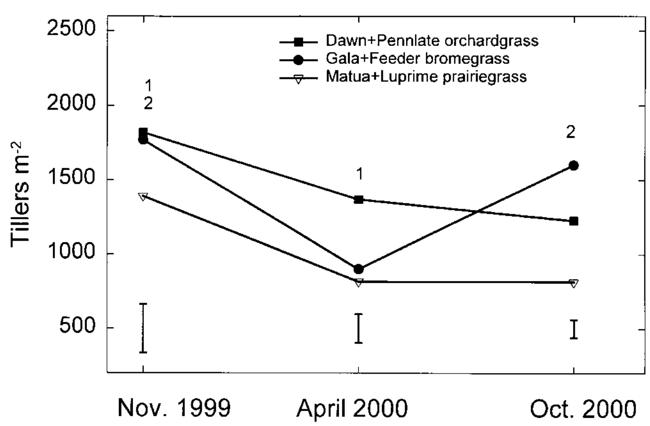

Fig. 7. Tiller density of grazing bromegrass, prairiegrass, and orchardgrass in the second field planting during November 1999 to October 2000 in field plots at Rock Springs, PA. Error bars indicate two standard error units for each date. Numbers at each date indicate significant ($P < 0.05$) contrasts: (1) Dawn and Pennlate orchardgrass vs. other grasses, and (2) Gala and Feeder grazing bromegrass vs. Matua and Luprime prairiegrass.

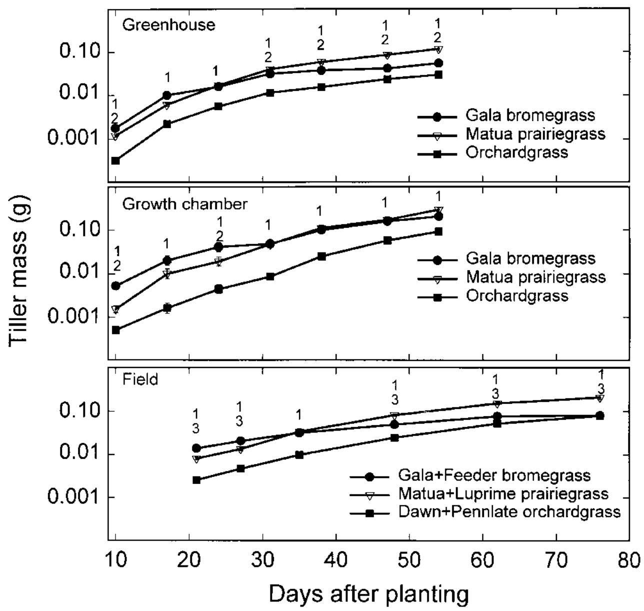

Fig. 8. Tiller mass of grazing bromegrass, prairiegrass, and orchardgrass during seedling development in controlled environment and field experiments. Error bars indicate two standard error units. Some error bars may not be visible because they are smaller than the symbols. Data were nonnormally distributed and log10 transformed for analysis. Note that the *y* axis is on a log10 scale. Numbers at each date indicate significant ($P < 0.05$) contrasts. Contrasts in the greenhouse and growth chamber were: (1) Matua prairiegrass and Gala grazing bromegrass vs. orchardgrass cultivars, and (2) Matua prairiegrass vs. Gala grazing bromegrass. Contrasts for the field data were: (1) Dawn and Pennlate orchardgrass vs. other grasses, (2) Dawn vs. Pennlate, (3) Gala and Feeder grazing bromegrass vs. Matua and Luprime prairiegrass, (4) Luprime vs. Matua, and (5) Feeder vs. Gala.

also noted greater seedling growth in Matua prairiegrass compared with perennial ryegrass and orchardgrass, and they attributed this to differences in seed mass. Matua prairiegrass had a higher seed mass than perennial ryegrass, which was heavier than orchardgrass. Shoot mass, leaf area, and root mass of seedlings in that study were positively correlated with endosperm and embryo mass of the seed. We observed a similar response with the larger-seeded prairiegrasses (mean seed mass of 10 mg) and grazing bromegrass (mean seed mass of 12 mg) having larger seedlings than orchardgrass (avg. seed mass of 1 mg). Final success in seedling establishment, however, did not appear to be related to seed mass, as has also been observed for switchgrass (*Panicum virgatum* L.) seedling establishment (Smart and Moser, 1999).

Our data, along with the report of Sangakkara et al. (1985), suggest that the larger seeded grasses, such as Gala and Matua, would establish quickly and have a competitive advantage over small-seeded grasses, such as orchardgrass, during establishment. If these species were part of a diverse seeding mixture, the larger seedlings would probably dominate the mixture and crowd out smaller-seeded grasses. Prairiegrass and grazing bromegrass probably should be included at a lower seeding rate or perhaps not used in seed mixtures with small-seeded grasses. This assumes that competitive interactions among seedlings limit establishment in all environments. Recent evidence from our laboratory demonstrates that under warm-dry conditions, facilitative interactions may occur among seedlings of some cool-season grasses and legumes, which enhance their establishment (Skinner, 1999).

Finally, our data indicate that seedlings of these grasses should be fully established by 40 to 50 DAP (30 to 40 d after emergence) under favorable moisture and temperatures in the spring and late summer. Seedling development in the fall, however, may be slower than that in the spring, which would result in delayed establishment and possibly low winter survival.

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